

access subsea, several approaches may be used. One may freedive in the manner of whales and dolphins, by taking a deep breath and diving as deep and long as lung and muscle power will allow. Using scuba and saturation diving techniques, depth and time can be dramatically increased. For access to depths beyond a thousand feet, it is necessary to use a submarine, the underwater equivalent of an airplane, a self-contained protective system supplied with air maintained at one atmosphere.

In the past decade, the use of remotely operated systems and robotic devices has begun to complement the direct approach of "man-in-the-sea." Presently, more than 700 remotely operated vehicles ("ROVs") are in active use worldwide, mostly for military and commercial applications, but increasingly, for research and exploration as well. One of the most sophisticated of these is the *Argo*, operated by Woods Hole Oceanographic Institution and involved recently in the discovery and documentation of the sunken liner, *Titanic*. Presently, such systems are tethered, with a pilot guiding operations from a surface station. Autonomous, computer-driven systems are being designed that will be equipped with camera eyes and various sensory devices to gather information and react to circumstances encountered without moment-by-moment directions from a human being.

Half a century ago, the relative state of technology developed for access to the skies and to the seas was roughly equivalent. Aerospace technology has advanced enormously during the past half century, but among ocean engineers, it is still regarded as an event of some note to descend 3000 feet in a small submersible, although the first visit to such depths occurred in the early 1930's.

Much has been happening in the past decade, however. I shall recap some highlights of this era, concentrating on technology that I've been involved with, that coincidentally tells the story of recent advances and future directions.

The demands of the offshore oil and gas

industry stimulated development of various new technologies, starting in the early 1970's. Saturation diving, originally a concept developed to prolong time subsea for scientific research and military applications, grew into a major industry. Oil rig operators paid more than \$50,000 per day to keep a team of men ready to work in depths as great as 1000 feet, sometimes to 1500 feet, using exotic mixtures of compressed gas and complex life support equipment.

Various four to six passenger submersibles were also developed to work underwater and to transport divers under pressure from one site to another. Costs of operation—\$20,000 to \$50,000 per day—included a large support vessel capable of withstanding the rigorous offshore environment.

At the time I was an inexperienced engineer who aspired to design airplanes, but got involved instead working with torpedoes and diver propulsion systems for the Royal Navy. A small group of people became interested in reconfiguring the one man portable iron dress system, called *Jim*, to work on oil rigs, and engaged me for design work. *Jim* was originally developed in the early 1930's for salvaging the sunken vessel, *Lusitania*. After initial success, it remained idle until redesigned in the early 1970's. There are now 15 units working worldwide.

A man using *Jim* can go deeper than divers—2000 feet—and can perform work at a much lower cost. The system can only walk on a flat surface, however, and work subsea often requires moving vertically. Thus came the inspiration for a system that ultimately became known as *Wasp*—it's yellow and black and, like its insect namesake, it flies. Eighteen *Wasp* units are presently in operation, but in 1976, when I set about designing the first, the concept seemed revolutionary.

Work began not in a grand engineering design facility, crammed with computers and draftsmen and secretaries. Actually, there was no electricity in my office, a derelict cottage by the seaside near Nor-

folk. The front door did not work, so I climbed in the window to get to my desk.

The place was quiet and peaceful, however, and within ten months of starting work, the first unit was ready to take to prospective customers. The cost of transporting *Wasp* from England to the Offshore Technology Conference in Houston was too great, so my colleagues and I took a large photograph and displayed it in a small booth among the giants of offshore industry.

*Wasp* created a minor sensation at its debut. Not only could it go twice as deep as most saturation divers—to 2000 feet it could also be operated for one tenth the cost. We thought everyone would like that. In fact, nobody did. The diving companies were quite happy charging \$50,000 a day and did not much like the idea of getting only \$5000 for *Wasp*. They did not want to buy it, but neither did they want their competitors to have it. Within a few weeks, we were avidly courted by several large companies. This was very flattering at first. Then it became clear that they all wanted to buy that one machine and get exclusive rights to ensure that no more would be built. At that point, things began to get nasty. An American company sued us and a British one took the more straightforward approach and simply stole the only *Wasp* then in existence. The matter was happily resolved in the end, with the American company buying four full years of production. After two years, the original *Wasp* was recovered and sold at a nice profit.

I tell this story only to emphasize that not everybody welcomes technological advances that enhance working capability and also greatly reduce costs. We got through difficult times with *Wasp* largely because of our naivete and the sheer blazing conviction that is borne of righteous indignation.

Since all production of *Wasp* was locked up for several years, it was time to design something new. I set to work on another kind of one-man system, *Mantis*, launched in 1978. *Mantis* is quite different from the

anthropomorphic *Jim* and *Wasp*. They, like astronaut's suits, have articulated limbs operated by muscle power. The operator actually has his arms in metal sleeves. The operator of *Mantis* uses metal and plastic manipulators controlled from within the cylindrical pressure hull. The system is propelled by strategically positioned thrusters controlled by a push-button panel provided with arrows indicating directions.

Thirty *Mantis* systems have been produced and are employed throughout the world in support of the offshore oil and gas industry. *Mantis* is successful because it is small, easily transported and deployed, and there is working capability normally possible only in much larger, more costly submersibles. At the time *Mantis* was introduced, about twenty large submersibles were being operated from ships in the North Sea. They soon became commercially extinct because *Jim*, *Wasp*, *Mantis* and a growing fleet of ROV's could do the work required at a fraction of the cost of operating the large systems.

Except for a few large submersibles working primarily for science, this type of submersible has become obsolete. Among those that continue to perform sterling service for science are the Harbor Branch Foundation's Johnson-Sea-Link systems and Woods Hole Oceanographic Institution's *Alvin*.

Let's go back now to the questions raised at the beginning. Are we sitting here on a mountain, or is this a lowland? Is technology the limiting factor preventing us from gaining access to the sea, or is something else holding us back?

Taking the astronaut's view of the earth, it is obvious that the oceans dominate the planet. Taking the narrow perspective of earth-bound human beings, there is an impression that land dominates. It wasn't so long ago that the popular concept of the earth was that it is flat, bounded by corners, with a canopy of sky overhead. Proof that earth is round was disquieting to many, but acceptable as long as humans remained the center of the action. People